examined, and by at the same time maintaining a brilliantly illuminated patch in an adjoining part of the field of view. If therefore we use the combination N, Q, P, $P_1$ (*i.e.* if we remove the second quartz plate), we can, by turning the prism round, diminish to any required extent the intensity of the light in one pair of the complementary images, and at the same time increase that in the other pair. This is equivalent to the conditions of Helmholtz's experiments; and the tints in question will be found to be produced.

W. SPOTTISWOODE

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## VENUS'S FLY-TRAP (*Dionæa muscipula*) [*]

## II.

*Contractility of Dionæa.*—I have given you a general view of our plant and of its behaviour. We next proceed to examine more particularly that property of contracting when irritated to which the plant owes its faculty of catching insects, and to which my own investigations have been directed. Before beginning the experimental demonstration of the facts, I wish to lay before you some considerations relating to the nature of this property as it manifests itself in living beings belonging to both kingdoms.

We have to do here not merely with contractility but with irrito-contractility. The fact that the property requires two words to express it implies that there are two things to express, viz. (1) that contraction takes place, and (2) that it takes place in answer to irritation. As this is the case not only here, but in all other instances of animal or vegetable active motion, we recognise in physiology these two properties as fundamental: irritability, or *excitability*, and *contractility*, the former designating the property possessed by every living structure whatsoever of being excited to action (*i.e.* of having its stored-up force discharged) by some motion or disturbance from outside; the latter, that kind of discharge or action which results in change of form, and usually declares itself in the doing of mechanical work. This property of excitability, which, let me repeat, is common to all living structures, is, as we have seen, comparable in its simplest manifestations to that possessed by many chemical compounds (of explosiveness) and many mechanical contrivances (of going off or discharging when meddled with, as in the case of the rat-trap already referred to).

In physiology, as in the other sciences of observation, the process of investigation is, throughout, one of comparison. Not only do we proceed from first to last from the known towards the unknown, but what we speak of as our knowledge or understanding of any new fact consists simply in our being able to bring it into relation with other facts previously well ascertained and familiar, just as the geographer determines the position of a new locality by ascertaining its topographical relation to others already on the chart.

The comparison we have to make this evening is between the contractility displayed by the leaf of Dionæa and the contractility of muscle. I choose muscle as the standard of comparison, not merely because it is best known and has been investigated by the best physicists of our time, but because its properties are easily illustrated and understood. I shall be able to show that the resemblance between the contraction of muscle and that of the leaf is so wonderfully complete that the further we pursue the inquiry the more striking does it appear. Whether we bring the microscope to bear on the structural changes which accompany contraction, or employ the still more delicate instruments of research which you have before you this evening, in order to determine and measure the electrical changes which take place in connection with it, we find that the two processes correspond in every essential particular so closely, that we can have no doubt of their identity.

Muscle, like every other living tissue, is the seat, so long as it lives, of chemical changes, which, if the tissue is mature, consist entirely in the disintegration of chemical compounds and the dissipation of the force stored up in these compounds, in the form of heat or some other kind of motion. This happens when the muscle is at rest, but much more actively when it is contracting, in which condition it not only produces more heat than it produces at other times, but also may do—and, under ordinary circumstances, does—mechanical work; these effects of contraction of muscle are, of course, dependent in quantity on the chemical disintegration which goes on in its interior.

Again, muscle so long as it is in the living state is electromotive. This property it probably possesses in common with other living tissues, for it is very likely that every vital act is connected with electrical change in the living part. But in muscle, as well as other irritable and contractile tissues in animals, the manifestation of electromotive force is inseparably connected with the special function of the tissue, *i.e.* with contraction, the connection being of such a nature that the electromotive force expresses, not the work actually done at any given moment, but the capacity for work. Thus, so long as the muscle lives, its electromotive force is found to be on the whole proportional to its vigour. As it gradually loses its vitality, its power of contracting and its electromotive force disappear *pari passu*. When it contracts, the manifestation of electromotive force diminishes in proportion to the degree of contraction. But it is to be borne in mind that, although when the muscle or the leaf contracts electromotive force disappears and work is done, there is no reason for supposing that there is any conversion of the one effect into the other, or that the source of the force exercised by the organ in contracting is electrical.

The lecturer then proceeded to demonstrate the correspondence between the electrical phenomena which accompany muscular contraction, and those which are associated with the closing of the Dionæa leaf, by a series of experiments.[*]

1. The form of the gastrocnemius muscle of the frog, in the uncontracted state, was projected on the screen with the aid of the electric light. A contraction was then determined by passing through it a single opening induction shock. It was seen to shorten and to become proportionately broader.

[In contraction, the bulk of a muscle remains unaltered. Further, the change of shape of the whole muscle depends on an exactly similar change of shape of every particle of which it is composed. This might be inferred from the consideration that a muscle is not an apparatus made up of parts differing from each other in structure, but a mass of substance equally instinct with life in every part. We know it to be the case by direct observation, for if we observe living muscle in the act of contraction under the microscope (as can easily be done in the muscles of insects),[†] we see that each minutest fibre participates in the change of form. The same holds good as regards the plant. The agent in the contraction is, without doubt, the protoplasm of the cells of the contractile organs. In Dionæa this has not as yet been sufficiently investigated, but in Drosera Mr. Darwin has shown that when the hairs which project from the upper surface of the leaf, become "incurved" under the exciting influence of appropriate stimuli, the contents of the cells undergo a most peculiar

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[*] Continued from p. 107.

[*] The statements contained in the first part of this lecture, especially those relating to the mechanism of the closure of the Dionæa leaf and its digestion, are founded almost entirely on information which I owe to Mr. Darwin. The experiments which led to the discovery of the "leaf current" and its "negative variation" were made last autumn, Mr. Darwin having kindly furnished me with plants for the purpose.—J. B. S.

[†] See Schäfer "On the Contraction of the Muscles of the Water-beetle, Phil. Trans., vol. clxiii. p. 429, 1873.

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change of form and arrangement, which Mr. Darwin has described as "aggregation."]

2. The image reflected by the mirror of a Thomson's galvanometer having been thrown on the screen near its right edge, it was first shown that when a fraction of a voltaic current passed through the electrodes in a direction from the lecturer's right hand towards his left, the spot on the screen moved towards the left of his audience, The galvanometer having been shut off, a muscle was placed on the electrodes with its cut surface against the left (*e'*) electrode, and its natural surface against the right (*e*). On again connecting the electrodes with the galvanometer the spot flew off in the same direction as before.

3. The nerve of the muscle having been placed across two wires in connection with the ends of the secondary coil of a Du Bois' induction apparatus, was excited by induced currents, the muscle remaining on the electrodes. The spot returned towards its original position.

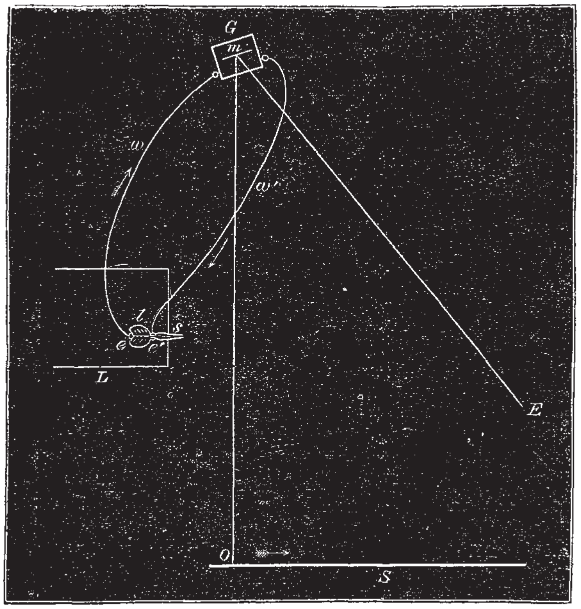

FIG. 1.—Diagram of the experiments.—S, screen facing the audience; E, position of electric light; G, reflecting galvanometer; *m* indicates the direction of the needle and of the mirror fixed to it; O, position of the bright image on the screen when no current exists in the galvanometer; L, end of the lecturer's table to his right; *e e'* his electrodes, on which the blade of the leaf *l* rests, with its stalk *s* towards the lecturer's right; *w w'*, wires leading to the galvanometer. The arrows show the direction in which the current flows through the galvanometer when the leaf is in the position shown. The arrow near O indicates the direction in which the spot of light moves under the influence of such a current.

[In both of these experiments only one-tenth of the muscle-current was allowed to pass through the galvanometer. The electrodes used, which are constructed on the same principle as those of Du Bois-Reymond, are shown in Fig. 2. The glass U-tubes A A' are half filled with saturated solution of sulphate of zinc. The zinc rods B B' are in metallic connection with the galvanometer ends by the wires W W'. The ends by which they dip into the solution are carefully amalgamated. The straight tubes C C' are of such width that they slip easily into the mouths of the U-tubes: they are prevented from going too far by rims of sealing-wax. These tubes are filled with a paste made by rubbing up modelling-clay with one per cent. solution of common salt. The electrodes are so supported that their distance and relative position can be varied with great facility.]

4. The heart of a frog was then placed with its apex against the left electrode (*e'*) and its base on the right (*e*). The spot moved in the same direction as before, but each heart-beat was marked by a sudden return of the needle towards its original position, indicating the instantaneous disappearance of electromotive force in the act of contraction. The effect corresponding to the contraction of the auricles could even be distinguished from that of the ventricular contraction which succeeded it.

5. A leaf of Dionæa, with its leaf-stalk still attached, was placed with its stalk end on the left electrode and its point on the right, as in Fig. 1. The direction of movement was the same.

6. The spot having assumed a fixed position on the screen, the leaf was excited by touching the sensitive hairs with a camel-hair pencil. The spot flew back towards the right edge of the screen, immediately afterwards returning to its original position. This effect was repeated several times.

7. The leaf-stalk was cut off, the leaf remaining as before on the electrodes. The deflection was increased (more than doubled). It was then explained that when the leaf-stalk is itself placed on the electrodes, the galvanometer indicates the existence of a current opposed in direction to that of the leaf, showing that the electrical conditions on opposite sides of the joint between stalk and leaf are antagonistic to each other. Consequently, so long as leaf and stalk are united, each prevents or diminishes the manifestation of electromotive force by the other. This is completely in accordance with what is observed with reference to nerve, and is known as "electrotonic variation of the nerve current."

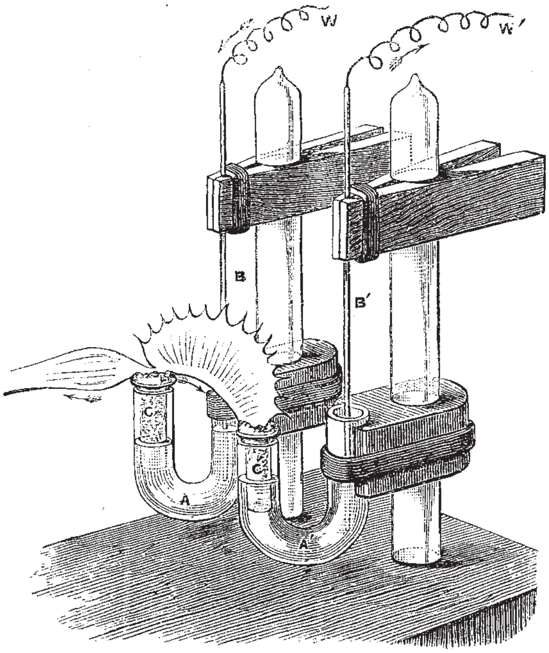

FIG. 2.—Non-polarisable electrodes employed in experiments on the Dionæa leaf.

8. Two fine-pointed electrodes, each in connection with one end of the secondary coil of the induction apparatus, were thrust into the centre of the external surface of a leaf, the ends of which rested on the electrodes of the galvanometer. On thus exciting the leaf the spot of light shot to the left, but it was observed that there was an obvious interval of time between the excitation and the effect. This period, though of much greater duration, corresponds to the so-called "period of latent stimulation" in muscle.

The plants exhibited and used for the experiments were provided by the kindness of the Director of the Royal Gardens, Kew.

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